# Mid-Frequency Reverberation Measurements with Full Companion Environmental Support

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## LONG-TERM GOALS

To understand mid-frequency (1-10 kHz) acoustics in shallow waters through measurements and modeling, including propagation, reflection, and forward- and backscatter, as well as reverberation. The top-level goals of this effort are to understand the important environmental processes that impact mid-frequency sonar performance in shallow water environments, and to develop means to efficiently collect those environmental data.

## OBJECTIVES

The overall goal is to conduct a reverberation experiment in very shallow water off the coast of Panama City, Florida in FY13. This field project is part of TREX (Target and REverberation eXperiment). The frequency range is 1-10 kHz, emphasizing 3-4 kHz. The Navy relevance is reflected in the fact that detection using mid-frequency sonar is in most cases reverberation limited. This project addresses a clear need in basic research for a 6.1 level measurement program, using well-controlled geometries and high resolution environmental measurements, designed (1) to test models predicting reverberation and (2) to quantify the most important environmental measurements to make in order to maintain accuracy in those predictions. Data from such the experiment will be used for testing various forward and inversion techniques, and could also be used for training purposes.

The water depth of the experiment is in the range of 15-25 m. The relevant water depth for naval applications covers the entire continental shelf. The key issue for reverberation is small grazing angle propagation and scattering in a waveguide. The major burden of such an experiment program is measuring the environment that influences reverberation. Reducing the region over which the environment needs to be measured becomes a primary consideration. By restricting the water depth to 15-25 m, the range at which the sound field is dominated by small grazing angle propagation and scattering is shorter than at deeper depths. Therefore, environmental measurements can be limited to a smaller area. Another advantage of working in such water depths is that diver support is available, which provides added control of the various measurements. Finally, from an environmental standpoint, the shorter ranges allow lower source levels to be used, and therefore the measurement program can be more easily made compatible with environmental regulations.

# Report Documentation Page

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Propagation and Scattering mechanisms to be addressed: Bottom roughness (including ripples); water column variability that affects propagation; surface roughness as a function of wind speed; fish school properties, and known clutter such as ship wreckage.

Supporting Environmental Measurements: Along the propagation path, sediment geo-acoustic parameters to a depth of 2-3 m, emphasizing the top 0.3 m because it has the most effect on long range reverberation; bottom roughness with depth resolution of 1 mm and range resolution of 1 cm; water column sound speed field over time; sea surface roughness as a function of time; and presence of fish schools and their characteristics over time.

## APPROACH

TREX13 was conducted in April-June, 2013, off the coast of Panama City, Florida, with participation from multiple institutions and involving three research vessels: The R/V Sharp and R/V Walton Smith from the US, and the Canadian Force Auxiliary Vessel Quest. This field effort endeavors to measure contemporaneously acoustic and adequate environmental data so detailed model/data comparison can be achieved, and important environmental factors can be identified for different applications. Figure 1 shows a simplified overview of TREX13. The color bathymetry is from the multi-beam survey (de Moustier) that was concentrated primarily on the along-shore Main Reverberation Track with focused environmental characterization, and secondarily on the Clutter Track where several wreck locations are known. The R/V Sharp was moored at 19 m depth where two sets of reverberation source and receiving array were deployed (Penn State and APL-UW). The R/V Walton Smith and the Quest moved along and about the two main tracks (Fig. 1) for source tows and various local acoustic and environmental measurements.

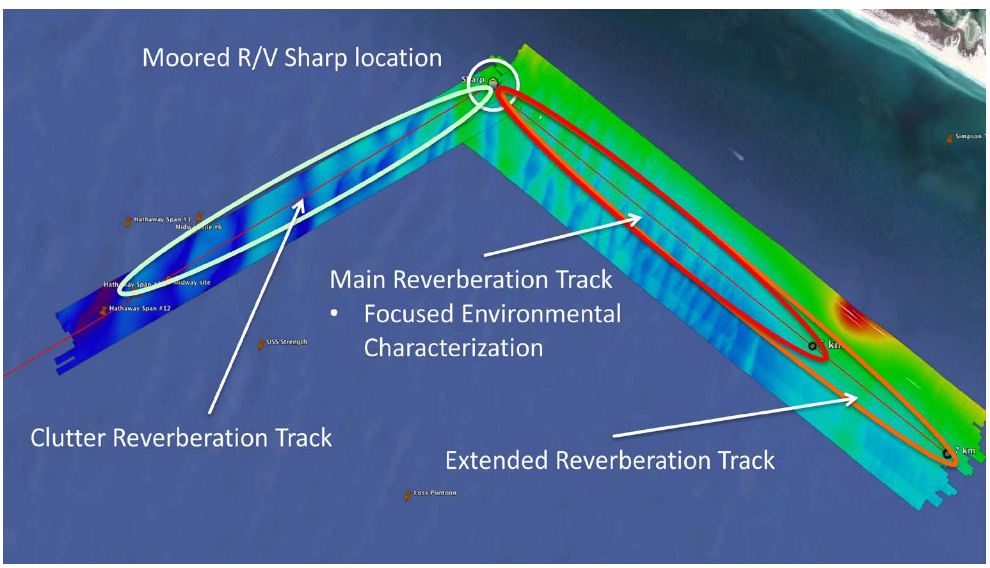


***Figure 1. Schematic of TREX13. The bathymetry from the multibeam survey is shown as two swaths with the color covering the depth range of 16-21 m. The Main Reverberation Track goes out to 5 km along shore where focused environmental characterization was conducted; the Extended Reverberation Track extends to 7 km. The Clutter Reverberation Track also goes out to 5 km perpendicular to shore.***

## WORK COMPLETED

The field experiment TREX was successfully conducted and data analysis and modeling is underway. A summary of various data set available for comprehensive analysis is given below.

Because reverberation consists of two-way propagation and a single backscatter, it is important to measure reverberation and propagation at the same time, as well as local bottom backscatter, in order to fully examine the reverberation process. Therefore, TREX13 was designed to collect all three categories of data: *reverberation*, *propagation*, and *local reflection* and *backscatter* along the reverberation tracks.

*Reverberation* was measured over a period of several weeks using fixed-fixed sources and receiving arrays at the Sharp site. Measurements focused primarily on the 2-4 kHz band using both CW and LFM waveforms, however, some signals at frequencies as high as 9 kHz were also recorded. The data were collected in groups of pings (with 100 to over 1000 individual pings within a group), and were recorded during all hours of the day, enabling study of reverberation variations over day-night, and under different weather conditions.

Several groups made *propagation* measurements along the main reverberation track, as depicted in Figure 2. Scripps Institution of Oceanography fielded three, 32-element vertical line arrays at ranges 0.5, 2.4, and 4.2 km from the moored R/V Sharp. These VLAs recorded the Sharp source's transmissions for use in propagation/forward scatter studies. DRDC's Quest made several runs with a towed echo repeater along the main and clutter tracks, hence providing simultaneous two-way propagation/reverberation data. In addition, two single element autonomous recorders, called Loggerheads, were deployed at the 5 and 6 km range, measuring propagation signals, as well as ambient noise.

Supplementing propagation measurements, which consist of multiple bounces from the surface and bottom boundaries, short range propagation and *local reflection* measurements were also made by several groups, including ARL-UT, Penn State, Scripps, and APL-UW (Figure 3). These measurements provided consistence constrains on the long range propagation models.

Finally, direct path *bottom backscatter* measurements were made in the band of 2-10 kHz at several patches along the main reverberation track, providing data on bottom scatter strength. One goal of the proposed effort is to use these measurements to determine the individual terms in the sonar equation and further constrain reverberation modeling.

Extensive environmental data were collected to support model/data comparison and Table I and II summarize the such data in the water column and on seafloor.

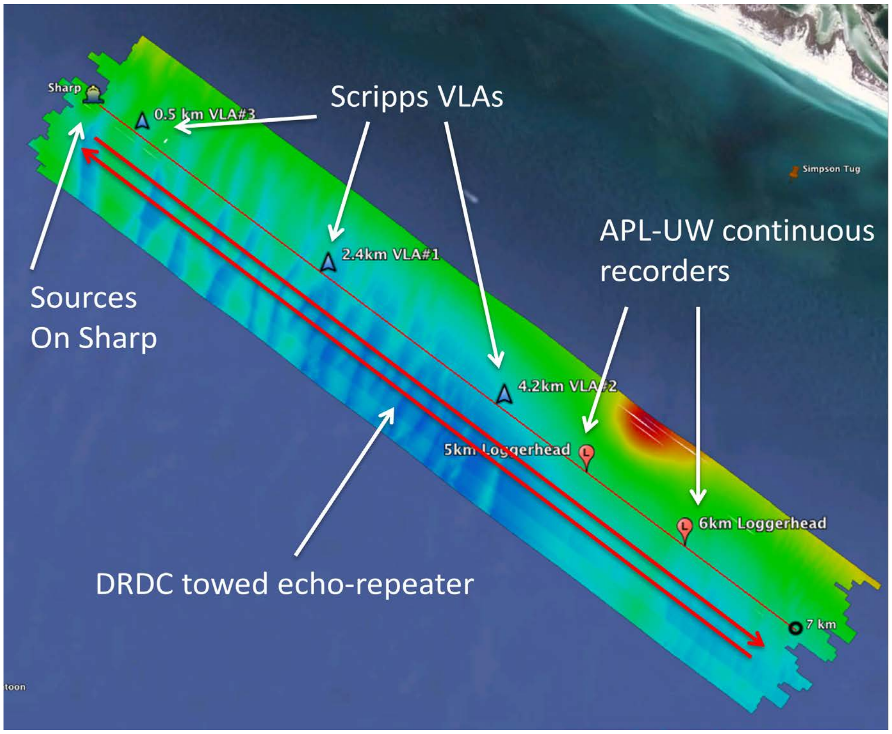


***Figure 2. Assets and tracks used in measuring propagation and forward scatter.***

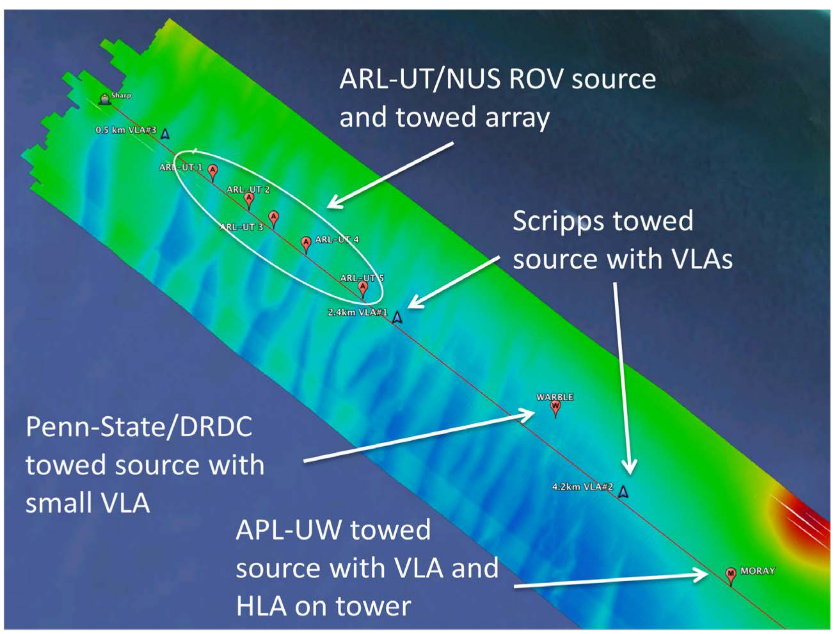


***Figure 3. Locations where supplemental short range propagation/reflection measurements were made.***

***Table I. Summary of environmental measurements***

## Environmental Characterization

- Oceanography
  - CTDs (Sharp, Smith, Quest)
  - ADCP (Quadpod)
  - Thermistors (Scripps VLAs)
  - Whitecap Camera (Scripps)
  - Wave Spectrum (APL-UW Waverider Buoys)
- Biologics
  - Ambient Noise (APL-UW autonomous recorders – "Loggerheads")
  - Echosounder Fish Survey (UW)
  - Broadband Reverberation (WHOI)

***Table II. Summary of Seabed measurements***

## Seabed Characterization

- Seabed Bathymetry/Roughness
  - Multibeam Survey (HLS)
  - ROV Laser-Line Scanner (ARL-UT)
  - Fixed-base Laser-Line Scanner (APL-UW)
- Seabed Spatial Distribution
  - Multibeam Survey (HLS)
  - Diver Cores (APL-UW)
- Seabed Subbottom
  - 2011 Chirp Survey (UT)
  - BOSS survey (NSWC)
  - Conductivity Probe (APL-UW)
- Sediment Sound Speed
  - SAMS (APL-UW)
  - WARBLE (Penn State)
  - Reflectivity (ARL-UT/NUS)

**RESULTS**

Some of the initial results from TREX are summarized below

1. One of the main goals of TREX is to understand effect of rough sea surface due to wind on reverberation. Models predict that with increasing wind, reverberation should decrease due to surface forward scatter. Fig.4 demonstrates measured reverberation as a function of time under two different wind conditions. While the trend is consistent with model predictions, follow on modeling should provide detailed quantitative comparison.

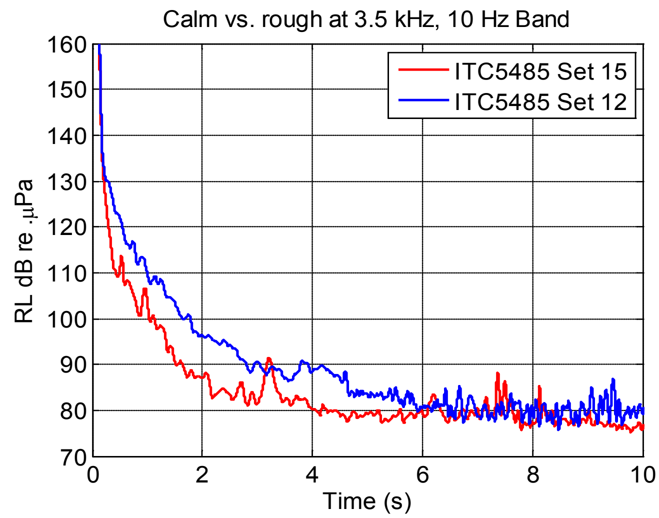


***Figure 4. Reverberation Level under calm (blue) and windy (red) conditions.***

2. TREX obtained bottom topographic data at different resolutions, and acoustic propagation and reverberation data were also obtained in same area. This offers an opportunity to study bottom topography on propagation (Transmission Loss) and reverberation. Fig. 5 shows a one-dimensional slice of TREX topography along the main reverberation track, and modeling using these different bottom data will lead into insight as to what a necessary bottom information in order to make adequate model predictions.

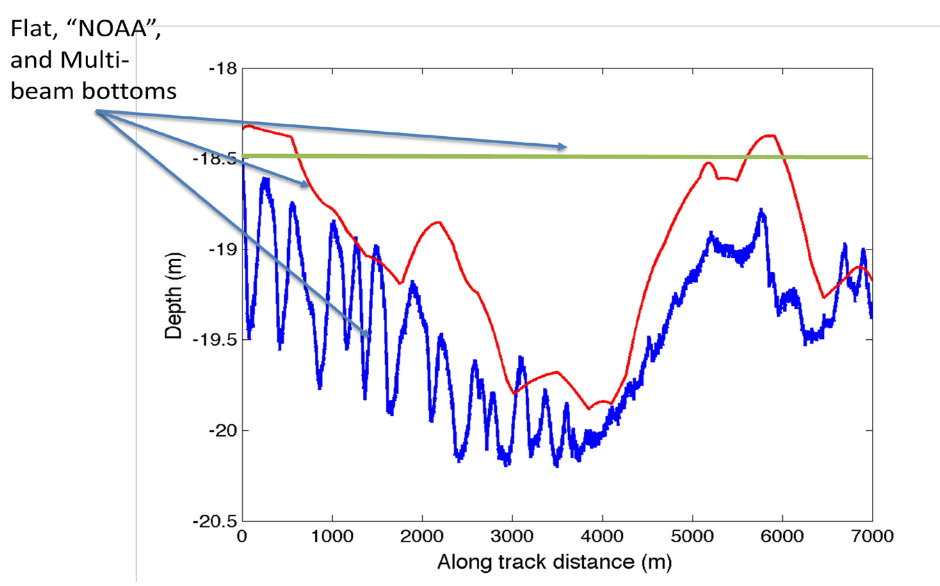


***Figure 5. Water depth along the 129 degree main reverberation track. Flat bottom model (green), coarse data from NOAA data base (red), and multibeam data ( blue, by de Moustier).***

3. Reverberation was measured over multiple weeks along the main reverberation track where detailed environmental data were contemporaneously measured. Fig.6 shows measured reverberation level along the direction of the main reverberation track over several hours. It shows a clear correlation to the bottom topography from the multibeam data as shown in

Fig. 5. Understanding the mechanism of this correlation will be part of our analysis to follow.

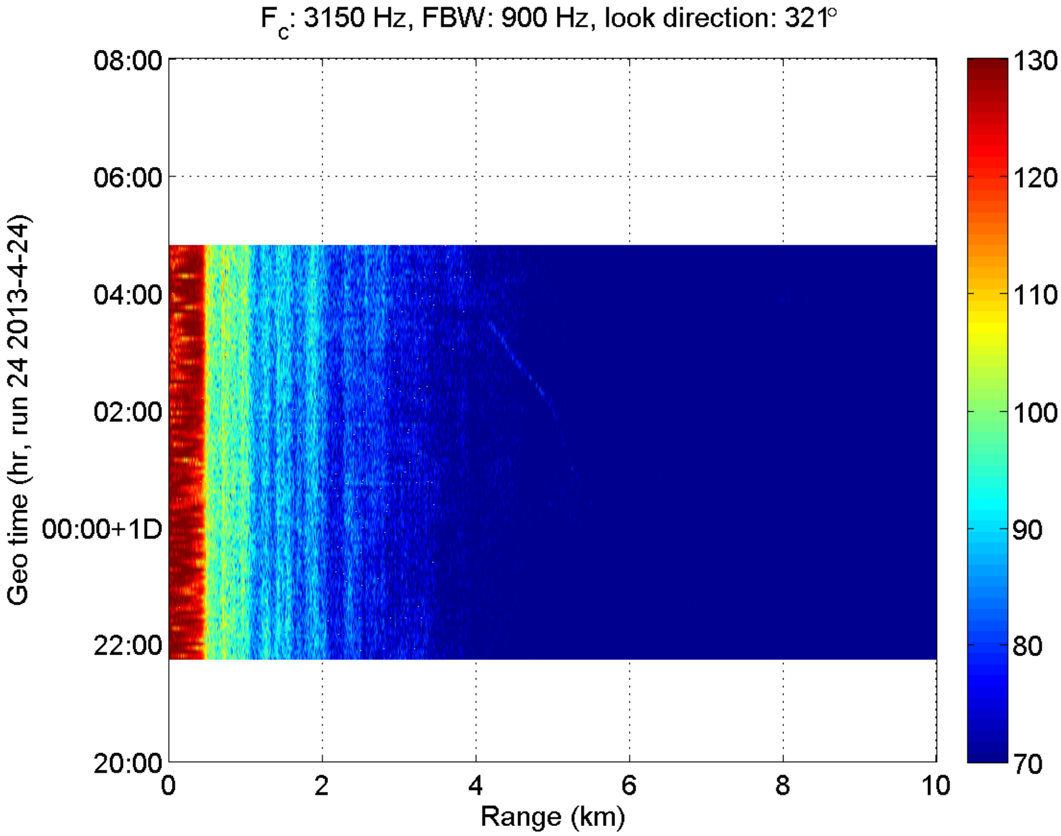


***Figure 6. Reverberation level (dB re muPa) as a function of range along the main reverberation track. The vertical axis is slow time indication different transmissions. Both the source and receive array are fixed in space.***

## IMPACT/APPLICATIONS

Naval active sonar detection is often reverberation limited. Understanding the main mechanisms that cause the diffuse reverberation will lead to better sonar performance.Theoretical and numerical progress inspired by the field work will find applications toward detection in shallow water areas including operational recommendations of the most important environmental measurements to make in order to maintain accuracy in predictions of reverberation.

## RELATED PROJECTS

NAVOCEANO data bases

ONR Signal processing code, active

"High Fidelity Finite Element Modeling for the Identification of Low- to Mid-Frequency Proud and Buried Object Elastic Responses and SAS Image Features," ONR Grant #: N62909-10-1-7153, PI: M. Zampolli

“Reverberation, sediment acoustics, and targets-in-the-environment,” ONR Grant #: N00014-11-1-0428, PI: K. L. Williams.

“Full Scale Measurement and Modeling of the Acoustic Response of Proud and Buried Munitions at Frequencies from 1-30 kHz,” SERDP Contract #: W912HQ-09-C-0027, PI: S. G. Kargl

**PUBLICATIONS**


1. Henyey, F. S., and D. Tang, “Reverberation clutter induced by nonlinear internal waves in shallow water,” *J. Acoust. Soc. Am.* **131**, EL302-308 (2013).
2. Tang, D., and D. R. Jackson, “Application of Small-Roughness Perturbation Theory to Range-Dependent Waveguides,” J. Acoust. Soc. Am., **134 (4)**, 289- 293 (2013).
3. Jie Yang, Darrell R. Jackson, and Dajun Tang, “Mid-frequency geoacoustic inversion using bottom loss data from the Shallow Water 2006 Experiment”, J. Acoust. Soc. Am. **131 (2)**, 1711-1721 (2012).
4. Tang, D., and B. T. Hefner, “Modeling backscatter from a series of sediment rough interfaces by a normal incident chirp sonar,”J. Acoust. Soc. Am., **131**, EL302-308 (2012)
5. Tang, D., F.S. Henyey, D. Rouseff, and J. Yang, “Single-path mid-frequency acoustic intensity fluctuations in shallow water, ”J. Acoust. Soc. Am., (In preparation).
6. Henyey F., K Williams, J. Yang,and D. Tang, “Simultaneous nearby measurements of acoustic propagation and high-resolution sound speed structure containing internal waves,” *IEEE J. of Oceanic Engineering*, Vol. 35, 684-694 (2010).
7. Yang, J., D. Rouseff, D. Tang, and F. S. Henyey, “Effect of the internal tide on acoustic transmission loss at mid-frequencies”, *IEEE J. Oceanic Engineering,* Vol. 35, 3-11 (2010).